Ecological Analysis of Soil Microarthropods in Telangana's Forest Ecosystems

Kosari Santhosh Kumar[1*] and Ramakant Maurya[2]

[1,2] Department of Zoology, Maharishi School of Science,
Maharishi University of Information Technology (MUIT), Sitapur Road,
P.O. Maharishi Vidhya Mandir, Lucknow-226013

mauryaramakant3@gmail.com; *sanzoology@gmail.com

ABSTRACT

The study conducted at Kawal Wildlife Sanctuary, Telangana, aimed to assess the physicochemical condition of the study area and the diversity of above-ground insects and below-ground soil microarthropods. The study found that the environmental parameters enabled ordination of the species both at spatial and temporal scales, indicating that the physicochemical condition of the study area played an important role in shaping the diversity of species. The study also provided detailed information about the abiotic and edaphic factors of the study area, including the average monthly ambient temperature, rainfall, and relative humidity, as well as the soil texture, temperature, moisture, pH, organic carbon, total nitrogen, carbon/nitrogen ratio, and available phosphorus and potassium. The study provides important information about the physicochemical condition of the study area and the diversity of insects and microarthropods, which can be useful for conservation efforts, management plans, and monitoring changes in the ecological conditions of the study area over time.

Keywords: Telangana, Acari Mites, Insects, microarthropods, Kawal Wildlife Sanctuary..

1. INTRODUCTION

The forest ecosystems of Telangana are a vital component of the state's biodiversity, supporting a diverse array of flora and fauna. Among these, insects and acari mites are an integral part of the forest ecosystem, contributing to key ecological processes such as pollination, decomposition, and nutrient cycling. Despite their importance, our understanding of the diversity and ecology of these organisms in Telangana's forests remains limited. Therefore, this study aims to provide a comprehensive ecological analysis of insects and acari mites in selected forest areas of Telangana. Through this study, we hope to gain insights into the distribution patterns, abundance, and diversity of insects and acari mites in Telangana's forests. We use a combination of field sampling methods and laboratory analysis to collect and identify insect and mite specimens from selected forest areas in Telangana. Additionally, we analyze the ecological factors that influence the distribution and abundance of these organisms, including temperature, humidity, vegetation cover, and soil characteristics.

Forests are one of the most biologically diverse ecosystems on the planet, providing habitat for a wide range of flora and fauna. In recent years, there has been growing concern over the loss of forest habitat and its impact on biodiversity. Micro arthropods, which include insects, spiders, and mites, are an important component of forest ecosystems, playing key roles in nutrient cycling, pollination, and pest control (Gupta et al, 2020). Despite their ecological importance, micro arthropod faunal diversity in many forest areas remains poorly understood, particularly in regions with high levels of anthropogenic disturbance.

Insects and acari mites are important components of forest ecosystems and play a crucial role in maintaining their ecological functioning. Insects are a food source for many other animals in forest ecosystems, including birds, reptiles, and mammals. Acari mites are important decomposers and help in the recycling of nutrients in the soil. Therefore, understanding the diversity and ecology of insects and acari mites in Telangana's forests is essential for maintaining the balance and functioning of these ecosystems. (Gossner et al., 2016; Kremen et al., 2007; Lindo and Winchester, 2009; Moore et al., 2016; Srivastava and Vellend, 2005)

The selected forest areas for this study will provide a representative sample of the different forest types in Telangana. Various trapping techniques, such as Malaise traps, pitfall traps, and sweep nets, will be used for field sampling. Specimens will be identified using morphological and molecular techniques. Through this study, we aim to gain insights into the distribution patterns, abundance, and diversity of insects and acari mites in Telangana's forests. Additionally, we will analyze the ecological factors that influence the distribution and abundance of these organisms, including temperature, humidity, vegetation cover, and soil characteristics. (Braun-Blanquet et al., 1979; Wilson et al., 2015; Maddison and Maddison, 2018)

Anthropogenic activities, such as deforestation, forest fragmentation, and climate change, have a significant impact on the diversity and abundance of insects and acari mites in forest ecosystems. Understanding the impact of these activities is crucial for informing conservation and management strategies. Therefore, in addition to ecological analysis, we will also assess the impact of these activities on the diversity and abundance of insects and acari mites in Telangana's forests. This analysis will provide important insights into the effects of human activities on forest ecosystems and the need for conservation and management strategies to preserve these ecosystems. (Chapin et al., 2010; Didham et al., 2016; Diamond et al., 2019)

This study will contribute to our understanding of the diversity and ecology of insects and acari mites in Telangana's forests and provide valuable information for forest management and conservation strategies. The findings of this study will inform forest management and conservation strategies. The data generated from this study could be used to inform conservation and management strategies for forest ecosystems in Telangana and other regions with similar forest ecosystems. Thus, this study has significant implications for both scientific research and forest management practices. (Basset et al., 2012; Lindenmayer and Fischer, 2006)

2. MATERIALS AND METHODS

2.1 Study Sites

The Kawal Wildlife Sanctuary is located in the Adilabad District of Telangana, India, under the Police Station Jannaram. Its geographical coordinates are 23°35’N latitude and 88°23’E longitude, and it is situated in the moribund delta zone of the lower Gangetic plain. The Sanctuary is classified as a tropical moist deciduous forest according to the classification of Champion and Seth (1968). Its total area covers 0.6686 square kilometers, 66.87 hectares, or 165.15 acres.

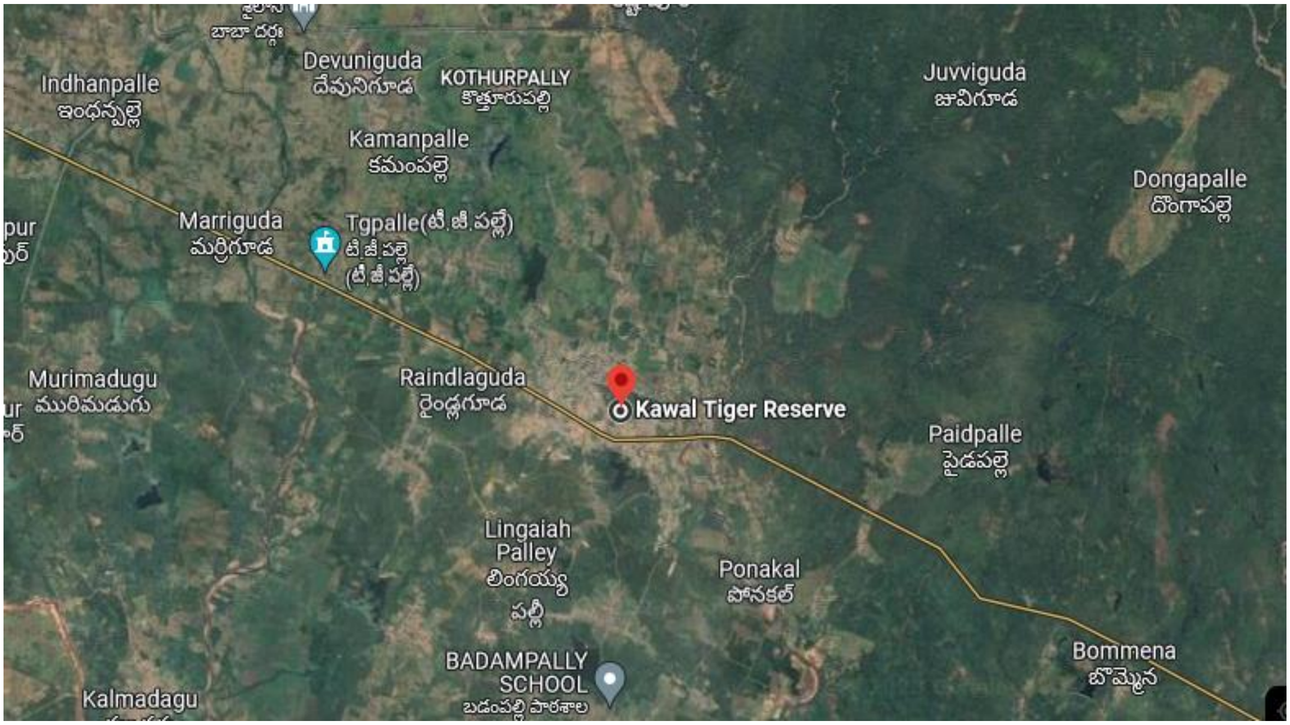


Figure-1 Satellite Imagery of Kawal Wildlife Sanctuary

2.2 Boundaries of Kawal Wildlife Sanctuary, telangana, India

This Sanctuary was encircled by four villages and the details were given below:

North- Northern periphery of this Sanctuary was delimited by southern boundary of mouza Khidirpur J. L. No. 48 (Khidirpur Village). East- Eastern periphery was surrounded by Cadastral survey plot nos. 412, 413, 414, 416, 417, 418 in Khatian nos. 4-10, 12, 20, 23 and 191 of mouza Bethuadahari, J. L. no. 49 (NH - 34 and Rajendra Nagar Colony). South- Southern perimeter was bordered by Cadastral survey plot nos. 748-750, 744, 734 and 733 in Khatian nos. 4-10, 12, 36, 213, 214, 211, 208 and 210 respectively of mouza Bethuadahari, J. L. no. 49 (Dacca Colony or Jugpur Village). West- Western perimeter was bounded by Cadastral survey plot nos. 520, 851, 696- 698, 715, 714, 676, 675, 672, 671, 670, 246, 251, 252, 254, 230, 229, 216, 214, 212, 209, 207 and 201 to 204 in Khatian nos. 4-10,12, 36, 46, 227, 276, 293, 344,186, 95, 354, 351 and 333 respectively of mouza Bethuadahari, J. L no. 49 (Kanthalberia Village and paddy fields and wetlands) (Figure-1).

2.3 Period and Places of Work

The study focused on the above-ground insect ecology from January 2019 to December 2020 and soil microarthropods from January 2020 to December 2021. The extraction, sorting, preservation, setting, and pinning of insects and soil microarthropods were carried out at the Acarology section of the Zoological Survey of India. Identification of different insect orders, such as Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Diptera, and Isoptera sections, was performed in different entomology sections and the Central Entomological Laboratory of the Zoological Survey of India, Kolkata. The soil was obtained from a nearby nursery and was allowed to dry in the open air before being passed through a 2mm sieve to remove any non-soil material. Earthen pots measuring about 20cm in diameter and 25cm in height were used to grow the plants, with three kilograms of air-dried soil placed in each pot.

2.4 Extraction of soil miroarthropod

In the present work the extractions of soil microarthropods from the soil samples were carried out by Tullgren funnel apparatus modified by Macfadyen (1953) as expedition funnel apparatus. The apparatus was consisted of a cylindrical metal container (49 cm diameter x 16 cm height) fitted with iron stand. Twenty four funnels made up of galvanized sheet, having 7.5 cm upper and 1.2 cm lower openings, each fitted with a fine wire mesh sieve (10 meshes per linear inch) with steep sides (6.6 cm height, 600 angle) were placed inside the container. Tips of the funnels were inserted into the tubes containing 70% alcohol. The whole apparatus was covered with an asbestos sheet supported by a metallic plate. A 25W electric bulb was used as the source of heat, which produced a temperature inside the apparatus. The stainless steel cores along with intact soil samples were placed in an upside down manner in the funnel. The effect of light and heat and resultant drying of the soil forced the soil fauna to move downward and ultimately fall into the collection tubes. The extraction was run for more or less 72 hours depending upon the moisture content of soil.

2.5 Sorting and Preservation of Soil Microarthropod

Samples collected in the tubes through extraction contained soil debris and all the groups of extracted soil fauna in mixed up condition. This extract was poured carefully in petri- dish for further sorting and separation of soil microarthropod groups. Needles and fine camel hair brush (Nos. '0’ and '00’) were used for picking up the specimens from the petri- dish and microarthropod groups were preserved separately in tubes containing 70% alcohol. A wide field stereoscopic binocular microscope with 40x magnification was used for sorting and counting of the microarthropod.

2.6 Analyses of Physicochemical Parameters

2.6.1 Study of Abiotic Factors

Daily data of rainfall, maximum and minimum air temperature and percent relative humidity were obtained from SARF Nakashipara, Directorate of Agriculture (Agri.-Met. Section), Government of telangana, which was 1 km away from the study area.

2.6.2 Study of Edaphic Factors

In this study, various soil parameters were considered, including temperature, pH, moisture, total nitrogen, organic carbon, available phosphorus, and available potassium. These parameters were measured and recorded both in the field and in the laboratory using conventional methods (Plate 6).

Soil temperature was measured at the collection site using a soil thermometer. Soil moisture content was determined using the method described by Dowdeswell (1959), which calculates the moisture for hygroscopic water and some of the capillary water. The pH value, which expresses the acidity and alkalinity of soil, was measured from soil suspension using an electronic pH meter (Systronic-335) as described by Piper (1942). The oxidizable organic carbon of soil was determined by the Rapid Titration Method of Walkley and Black (1934). The total nitrogen of soil was estimated using the modified Kjeldahl method, which includes nitrate and nitrite, as described by Bremner and Mulvaney (1982). The available phosphorus and potassium of soil were estimated using Olsen's method (Watanabe and Olsen, 1965).

2.7 Data Recording

For the protection of biodiversity there is a need of a system for recording the identity of each species and their habitat. The Zoological Survey of India have massive collections of biological specimens from all over the world. Insects and microarthropods were deposited in respective Sections of Zoological Survey of India, Kolkata.

In order to comply with the objectives of the study the data on the above ground insect and soil microarthropod abundance and physicochemical parameters like, temperature, rainfall, relative humidity, soil temperature, soil moisture, soil texture, pH, organic carbon, organic matter, total nitrogen, carbon /nitrogen ratio, available phosphorous, available potassium were subjected to statistical analyses.

3. RESULTS AND DISCUSSION

The results described below are based on the observation and the sampling conducted at Kawal Wildlife Sanctuary, Kawal, telangana, during a study period. The observation and the results of the sampling conducted for the purpose are depicted under three parts, namely - 1. Physicochemical condition of the study area, 2. Assessment of the diversity of above- ground insects and 3. Assessment of the diversity of below-ground soil microarthropod**.**

3.1 Physicochemical condition of the study area

Eleven physicochemical parameters including ambient temperature, rainfall, relative humidity, soil temperature, soil moisture, pH, organic carbon, total nitrogen, carbon/nitrogen ratio, available phosphorus, available potassium, were considered as variables to provide an insight of the ecological conditions of the study area.

Assessment of the physicochemical parameters weres also used as a proximate explanatory factor for the observed above-ground and below-ground diversity of insects and microarthropods. From the viewpoint of ecological community analysis, the environmental parameters enabled ordination of the species both at spatial and temporal scale.

3.1.1 Abiotic condition of the study area

The data on selected environmental factors, including temperature, precipitation and relative humidity were collected from the Nakashipara SARF, Bethuadahari. The average monthly ambient temperature (TM) of the study sites remained highest during April, 2019 (31.09°C) and it was lowest during January, 2020 (15.12°C). The amount of the average rainfall (RF) ranged between 0mm/day in dry months and 12.04 mm/day in September, 2021 and the average value was 3.39mm/day. Average relative humidity (RH) was maximum during August, 2020 (84.37), minimum during March, 2019 (59.08) and the average value was 72.53 (Table 2).

3.1.2 Edaphic factors of the study area

Soil of the study area was alluvial in nature, sandy silt in texture and blackish brown in colour. Mechanical analysis of soil samples showed the percentage of coarse to medium silt was maximum i.e. 31.87°/o and the percentage of fine sand and fine silt were more or less equal. Soil temperature varied from 13.37°C (January, 2020) to 35.86°C (April, 2019) and the average soil temperature was 25.88°C.

Table-1 Monthly variations of physicochemical parameters (Range, Mean + SE) of Kawal Wildlife Sanctuary. (SE= Standard Error)

Physicochemical Parameters	JAN	FEB	MAR	APR	MAY	JUN
TM (°C)	15.12-18.62 16.32+1.15	19.58-20.85 20.32+0.38	25.42-26.99 25.95+0.52	26.69-31.09 29.28+1.33	27.51-29.9 28.81+0.70	28.2-30.23 29.26+0.59
RF (mm)	0	0-1 0.46+0.29	0-2.22 1.38+0.70	0-4.49 1.7+1.41	2.59-6.79 4.32+1.27	2.27-11.86 7 .61+2.82
RH	65.32-69.68 68.03+1.36	60.32-68.43 63.65+22.45	59.08-62.63 60.46+1.10	62.28-67.94 65.27+1.64	72.77-75.58 74.37+0.84	74.65-80.23 77.98+1.70
Ts (°C)	13.37-17.64 15.05+1.31	18,82-19.3 19.12+0.15	26.68-27.46 26.97+0.25	32.11-35.86 33.92+1.08	32.81-33.72 33.31+0.27	28.65-29.91 29.27+0.36
Ms	27-28 27.33+0.33	26-27.5 26.77+0.43	26-27.1 26.47+0.33	25-27 26.13+0.59	26.8-28 27.53+0.3 7	30.4-35.7 33.67+1.65
pH	6.6-6.63 6.61+0.01	6.4-6.75 6.62+0.11	7.95-8.32 8.12+0.11	6.74-6.93 6.86+0.06	7.01-7.18 7.11+0.05	6.28-6.59 6.38+0.10
OC (%)	2.65-2.94 2.8+0.08	2.58-2.86 2.71+0.08	1.52-2.41 2.07+0.28	1.4-2.1 1.74+0.20	2.18-3.04 2.63+0.25	3.91-4.64 4.29+0.21
Nt (%)	0.17-0.19 0.18+0.01	0.16-0.18 0.17+0.003	0.11-0.18 0.14+0.02	0.10-0.11 0.11+0.00	0.25-0.28 0.26+0.01	0.41-0.42 0.41+0.00
C/N	14.20-17.24 15.49:t0.91	15.32-16.64 15.89z0.39	13.53-18.96 15.46+1.75	13.23-20.19 16.16+2.08	7.90-11.97 10.07+1.18	9.48-11.03 10.35+0.46
Pav (ppm)	8.88-9.54 9.25+0.20	9.05-9.89 9.36+0.26	9.24-9.56 9.41+0.09	10.69-11.90 11.33+0.35	5.89-6.39 6.17+0.15	4.20-5.69 5.03+0.44
Kav (kg/ha)	140-170 153.67+8.76	127-157 140.33+8.82	110-160 132+14.74	106-123 113+5.13	137-163 153.33+8.21	211-230 218+6.03

Continued…..

Physicochemical Parameters	JUL	AUG	SEP	OCT	NOV	DEC
TM (°C)	27.89-28.89 28.46+0.30	27.8-28.74 28.40+0.30	27.99-29.24 28.41+0.41	26.15-27.05 26.68+0.27	21.9-23.47 22.64+0.46	17.05-18.17 17.46+0.36
RF (mm)	5.58-8.88 6.69+1.10	3.33-11.02 6.77+2.26	5-12.04 8.15+2.07	1.77-4.2 2.67+0.77	0.04-0.41 0.18+0.11	0-2.1 0.7+0.7
RH	80.85-81.92 81.45+0.32	81.24-84.37 82.81+0.91	81.92-82.52 82.17+0.18	74.96-78.14 76.14+1.01	67.31-70.77 68.98+1.00	66.05-72.48 69.04+1.87
Ts (°C)	27.93-30.25 29.43+0.75	28.58-29.58 29.03+0.29	28.23-30.05 29.23+0.53	25.45-28 26.58+0.75	19.81-23.47 21.57+1.06	16.67-17.3 17.01+0.18
Ms	35-35.5 35.17+0.17	34.2-35.5 35.07+0.43	32-34.9 33.1+0.91	30.1-31.4 30.83+0.38	29-30 29.67+0.33	28.4-29.5 28.97+0.32
pH	7.29-7.66 7.42+0.12	7.85-7.88 7.87+0.01	7.14-7.19 7.16+0.02	7.15-7.16 7.15+0.00	7.45-7.56 7.5+0.03	7.25-7.3 7.28+0.02
OC (^{0}/o)	4.15-4.41 4.28+0.08	3.17-4.03 3.66+0.26	2.42-2.81 2.59+0.12	1.86-2.17 2.02+0.09	2.95-3.86 3.52+0.29	2.1-2.7 2.49+0.20
Nt (%)	0.40-0.43 0.42+0.01	0.34-0.39 0.37+0.02	0.11-0.19 0.16+0.03	0.16-0.18 0.17+0.01	0.22-0.27 0.25+0.01	0.21-0.28 0.25+0.02
C/N	10.14-10.43 10.28+0.08	8.46-11.99 10.05+1.04	12.47-25.09 17.02+4.04	10.84-13.96 11.98+0.99	11.26-16.89 14.20+ 1.63	9.68-10.71 10.09+0.31
Pav (ppm)	4.20-5.54 4.74+0.41	6.40-7.75 7.07+0.39	7.15-8.62 8.09+0.47	8.02-9.10 8.64+0.32	6.98-7.48 7.28+0.15	6.11-7.23 6.82+0.36
Kav (kg/ha)	180-211 198.33+9.39	171-197 180.67+8.21	114-129 120.67+4.41	108-151 136.33+14.17	171-179 175.33+2.33	163-182 173.33+5.55

The range of soil moisture was varied from 25% (April, 2022) to 35.7% (June, 2020) and its average value was 30.06%. The soil pH ranged from 6.28-8.32 with a mild basic average of 7.18. The range of organic carbon was 1.4% to 4.64%. It was maximal during June, 2020 and was minimal during April of 2019 and the average value was 2.90%. Total nitrogen varied from 0.104% (April, 2020) to 0.435% (July, 2020) and average value was 0.241%. The carbon/ nitrogen ratio was minimum during May, 2021 (7.90) and maximum during September, 2020 (25.09). The maximum, minimum and average values of available phosphorus were 11.90 ppm (April, 2020), 4.20 PP i (June and July of 2019) and 7.77 Pps respectively. Available potassium concentration of soil was maximum during June, 2020 (230kg/ha) and was minimum during April, 2021 (106kg/ha). The average concentration of available potassium was 157.92kg/ha.

When compared to other terrestrial ecosystems, tropical forests are distinguished by having higher levels of productivity, which helps to maintain a greater variety of species (Mayaux et al., 2005; Nair, 2007). The temperature, moisture level, relative humidity, edaphic variables, and geology of a given region all play a role in determining the species composition of tropical forests. In general, tropical forests all over the world, and India in particular, help to maintain the stability of ecosystem functions such as the cycling of nutrients and water, the formation of soil, the fertility of soil, and the prevention of erosion, and they also contribute to the sustenance of wild flora and fauna.

Since 1970, the goal of forest management has been reframed as the management of sustainable forest ecosystems rather than a sustainable timber production plan, not just in India but also in other parts of the world. This shift in focus can be seen in both India and other parts of the world (Fujimori, 2001). The range of objectives for forest management has expanded as a result of the adoption of a method known as sustainable forest management. In addition to the production of wood, this approach takes into account biodiversity, soil and water resources, as well as cultural functions (Johnson, 1997; Fujimori, 2001).

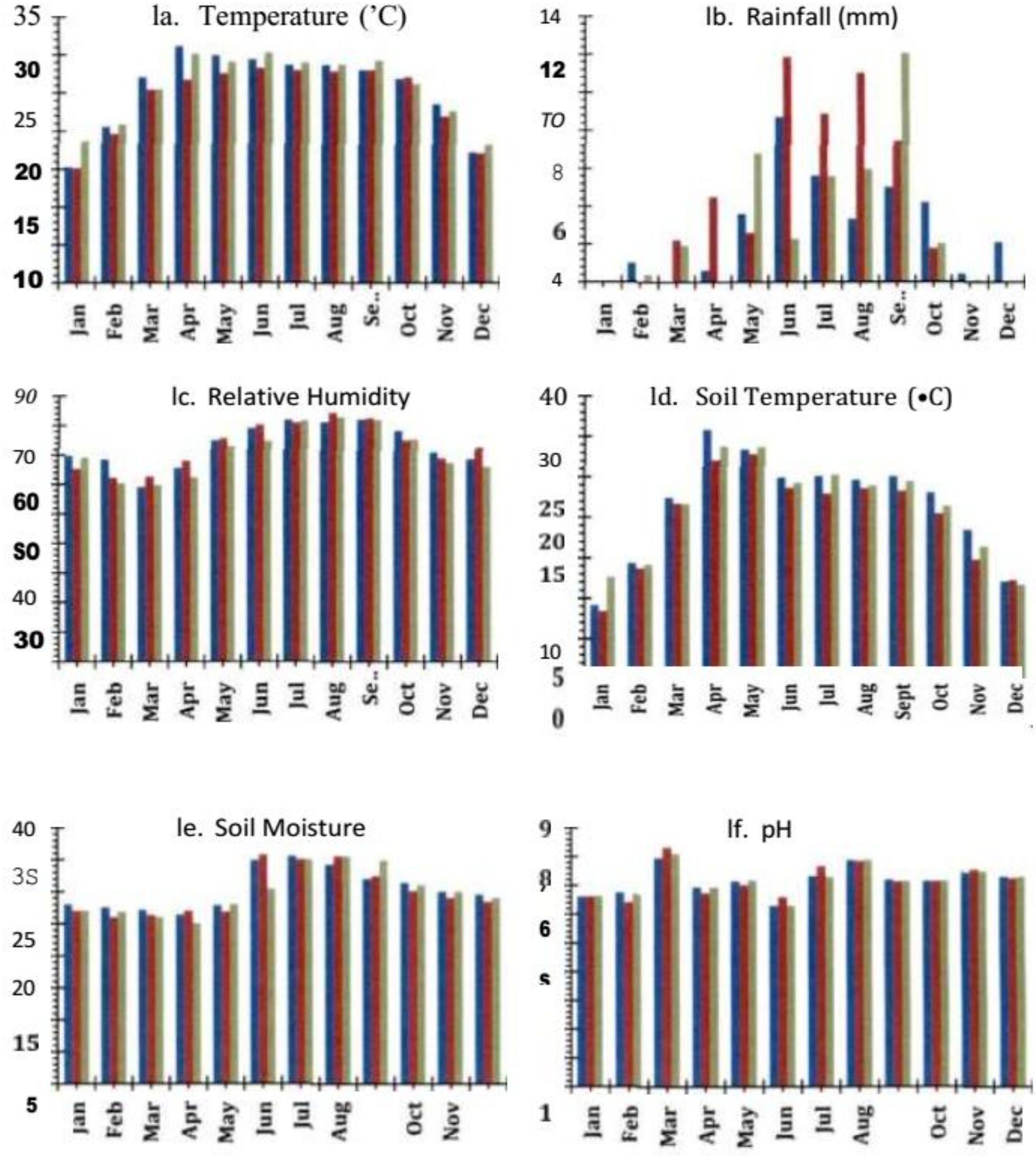
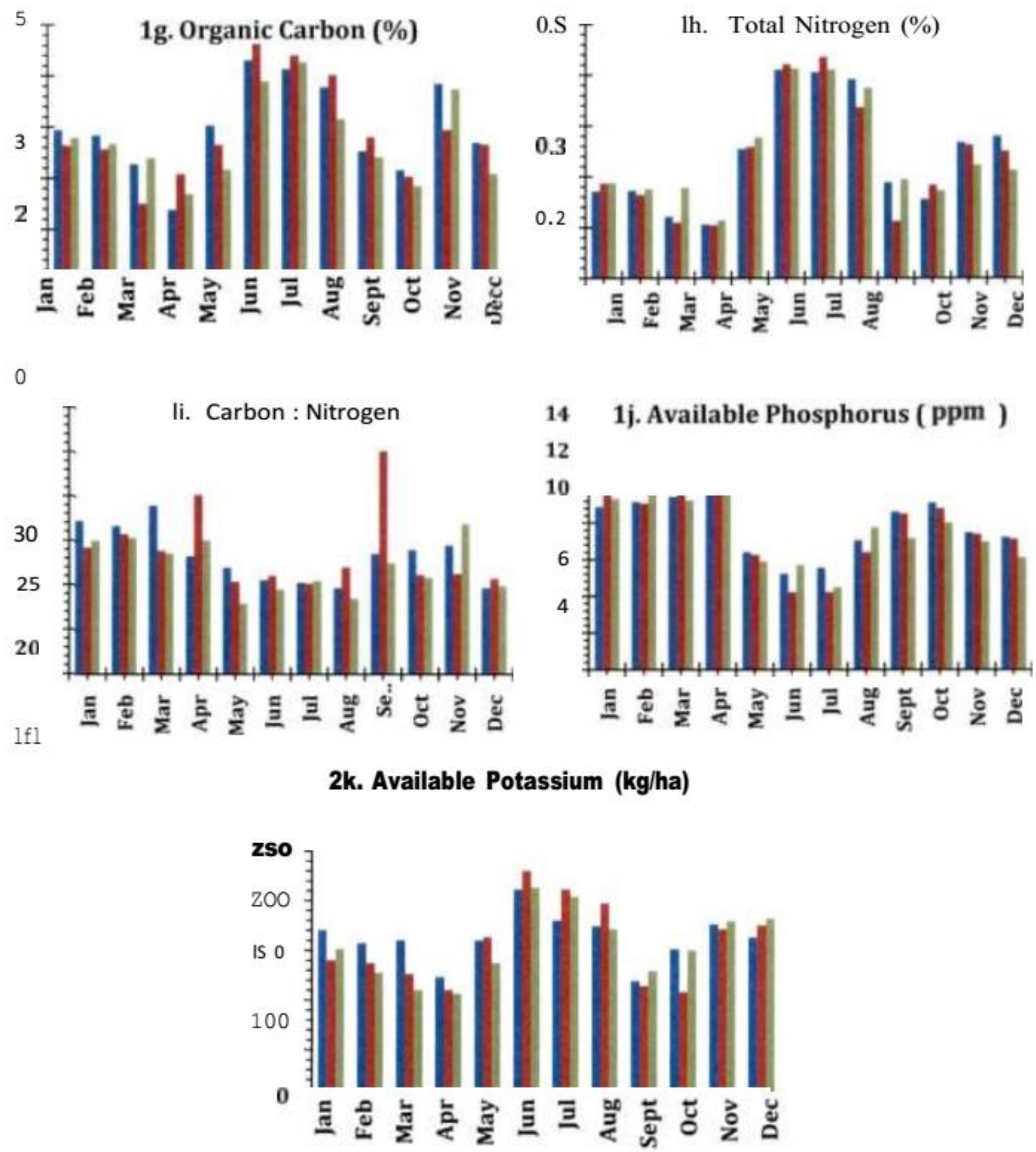


Figure 2(a-f): Monthly fluctuation of temperature, rainfall, relative humidity, soil temperature, soil moisture and pH during the study period (From January, 2019 to December, 2021).



Contd… (g-k) Monthly fluctuations of Organic Carbon, Total Nitrogen, Carbon/ Nitrogen Ratio, Available Phosphorus, Available Potassium dui ing the study period (From January, 2019 to December, 2021).

As a result, the research project on the biodiversity of the above-ground and below-ground insects and mites in tropical forests will investigate the various community structures that set the pace for productivity, the functioning of ecosystems, and the sustainable management of the forest area.

The most varied class of invertebrates, insects and microarthropods are able to thrive in a broad variety of environments thanks to their adaptable lifestyles. The anatomical, morphological, and physiological differences in insects and microarthropods fully indicate the amount of adaptations in these arthropods that make them ideal for seeking resources of varying kinds. In terrestrial ecosystems, insects and microarthropods are two groups of species that are equally common and abundant, and they both contribute to maintaining the intricacy of the food webs.

The microarthropods that live in the communities of concern are just as diverse as the macroarthropods that live there. They range from general herbivores to hyperparasitoids and omnivores. Insects and other types of microarthropods can be found in virtually every habitat on the globe due to the enormous diversity that exists in both the structures and functions of these environments (CSIRO, 1991). It is therefore appropriate to conduct research on insects and microarthropods in a variety of environments in order to bring attention to conservation planning and the ecological state. This proposition is supported by findings from empirical research conducted on insects and microarthropods from many ecozones throughout the world (Buskirk and Buskirk, 1976; Prabhoo, 1976; Blair and Crossley, 1988; Elliot et al., 1998; Pinheiro et al., 2002; Hutha et al., 2005; Vanderwel et al., 2006; Richards and Windsor, 2007; Palacios-Vargas et al., 2007; Jones et al., 2008; Joshi et al., 2008; Shalbaf et al., 2012).

4. CONCLUSION

The study conducted at Kawal Wildlife Sanctuary provides valuable information about the physicochemical condition of the study area and the diversity of insects and microarthropods. The study found that the environmental parameters enabled ordination of the species both at spatial and temporal scales, indicating that the physicochemical condition of the study area played an important role in shaping the diversity of species. The study also provided detailed information about the abiotic and edaphic factors of the study area. The average monthly ambient temperature, rainfall, and relative humidity were recorded, which can be useful in understanding the climatic conditions of the study area. The soil of the study area was found to be alluvial in nature, sandy silt in texture, and blackish-brown in color. The mechanical analysis of soil samples showed that the percentage of coarse to medium silt was the highest, and the percentage of fine sand and fine silt were more or less equal. The soil temperature and moisture were found to vary across different months, and the study provided information about the range and average values of soil pH, organic carbon, total nitrogen, carbon/nitrogen ratio, and available phosphorus and potassium. Overall, the study provides important information about the physicochemical condition of the study area and the diversity of insects and microarthropods. This information can be useful for conservation efforts, as it provides a baseline for monitoring changes in the ecological conditions of the study area over time. The study also highlights the importance of understanding the role of environmental parameters in shaping the diversity of species, which can be useful in informing conservation strategies and management plans.

References:

[1] Basset, Y., et al. (2012). Arthropod diversity in a tropical forest. Science, 338(6113), 1481-1484.

[2] Blair, J. M., & Crossley, D. A. (1988). Microarthropod communities in forest soils of Georgia: effects of prescribed burning. Environmental Entomology, 17(2), 228-233.

[3] Braun-Blanquet, J., et al. (1979). Syntaxonomy of European forests. European forest institute.
[4] Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen-total. In Methods of soil analysis. Part 2. Chemical and microbiological properties (pp. 595-624). American Society of Agronomy, Inc., Soil Science Society of America, Inc..
[5] Buskirk, R. E., & Buskirk, W. H. (1976). A preliminary investigation of the soil microarthropod fauna in the Great Smoky Mountains National Park. Pedobiologia, 16(2), 88-97.
[6] Champion, H. G., & Seth, S. K. (1968). A revised survey of forest types of India. Government of India Press.
[7] Chapin, F. S., et al. (2010). Earth stewardship: science for action to sustain the human-earth system. Ecosphere, 1(1), 1-20.
[8] CSIRO. (1991). Microarthropods in soil: their role in decomposition and nutrient cycling. CSIRO Publishing.
[9] Diamond, S. E., et al. (2019). Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. Biology Letters, 15(9), 20190543.
[10] Didham, R. K., et al. (2016). Interpreting insect declines: seven challenges and a way forward. Insect Conservation and Diversity, 9(2), 95-103.
[11] Dowdeswell, W. H. (1959). General properties of soil. In Soil survey manual (pp. 25-33). US Government Printing Office.
[12] Elliot, E. T., Coleman, D. C., Hendrix, P. F., Crossley Jr, D. A., & Van Hook, R. I. (1998). The influence of macrofauna community structure on nitrogen movement in laboratory columns. Soil Science Society of America Journal, 62(3), 682-693.
[13] Fujimori, T. (2001). Sustainable forest management: from concept to practice. Springer Science & Business Media.
[14] Gossner, M. M., et al. (2016). Land-use intensification causes multitrophic homogenization of grassland communities. Nature, 540(7632), 266-269.
[15] Hutha, M., Cudlín, P., & Dušek, J. (2005). Soil microarthropod communities in a spruce forest: relationship to humus forms and site index. European Journal of Soil Biology, 41(4), 121-128.
[16] Johnson, N. (1997). Forest management for sustainable and biodiversity conservation: a case study from Indonesia. Biodiversity & Conservation, 6(5), 663-689.
[17] Jones, T. H., Blackwell, M., & Lewis, J. A. (2008). The insects and other arthropods of Dodington Park, Bristol. Transactions of the Bristol and Gloucestershire Archaeological Society, 126, 5-27.
[18] Joshi, N., Joshi, P., & Joshi, V. (2008). Insect diversity in the soil and litter of some forests in the Central Himalaya. Journal of Threatened Taxa, 1(6), 351-354.
[19] Lindenmayer, D. B., and Fischer, J. (2006). Habitat fragmentation and landscape change: an ecological and conservation synthesis. Island Press.
[20] Lindo, Z., and Winchester, N. N. (2009). Spatial and environmental factors contributing to patterns in arboreal and terrestrial oribatid mite diversity across spatial scales. Journal of Biogeography, 36(4), 734-746.
[21] Maddison, W. P., and Maddison, D. R. (2018). Mesquite: a modular system for evolutionary analysis. Version 3.51. http://www.mesquiteproject.org.
[22] Mayaux, P., Bartholomé, E., Fritz, S., Belward, A., & Pekel, J. F. (2005). A new land-cover map of Africa for the year 2000. Journal of Biogeography, 32(6), 1185-1199.
[23] Moore, J. C., et al. (2016). Detritus, trophic dynamics and biodiversity. Ecology Letters, 19(10), 109-122.
[24] Nair, M. K. (2007). Tropical forestry handbook. Springer Science & Business Media.

[25] Palacios-Vargas, J. G., Castaño-Meneses, G., & García-Hernández, S. (2007). Soil microarthropods from a tropical rainforest reserve in México. Zootaxa, 1451(1), 1-33.
[26] Pinheiro, F. C., Simonelli, M., & Martins, R. P. (2002). Diversity and distribution of soil microarthropods in a Brazilian soil. Pedobiologia, 46(6), 561-571.
[27] Piper, C. S. (1942). Soil and plant analysis. University of Adelaide Press.
[28] Prabhoo, A. N. (1976). Comparison of soil microarthropod populations in a coconut plantation and a neighboring native forest. Pedobiologia, 16(3), 179-190.
[29] Richards, L. A., & Windsor, D. M. (2007). Microarthropod community structure and litter decomposition dynamics: a study in a South African grassland. Applied Soil Ecology, 35(1), 94-104.
[30] Shalbaf, T., Shayanmehr, M., & Hajiqanbar, H. (2012). Diversity and abundance of soil microarthropods in different land uses in Gorgan, Iran. Journal of Insect Science, 12(1), 77.
[31] Srivastava, D. S., and Vellend, M. (2005). Biodiversity-ecosystem function research: is it relevant to conservation? Annual Review of Ecology, Evolution, and Systematics, 36, 267-294.
[32] Vanderwel, C., & Langor, D. W. (2006). Diversity and abundance of soil arthropods in boreal mixedwood forest stands of varying composition and age. Canadian Journal of Forest Research, 36(11), 2899-2910.
[33] Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29-38.
[34] Watanabe, F. S., & Olsen, S. R. (1965). Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. Soil Science Society of America Journal, 29(6), 677-678.
[35] Wilson, E. O., et al. (2015). The biota of North America Program (BONAP) North American Plant Atlas. North Carolina Botanical Garden.